Impact of Indoor Environment Improvement on Comfort and Productivity in a Chipboard Workplace

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Abstract: A real example was investigated on the relationship between indoor environment, comfort and productivity in a chipboard workplace location in southern China. In this field study, a subjective evaluation and objective measurement were carried out before and after retrofit of the indoor environment in a chipboard workplace with area about 2707 m^2. 160 workers complained of, and often suffered from, labor damage in the workplace. Indoor environmental conditions were found to be very unsatisfactory for safety and health. Several aspects of the workplace environment were improved, including ventilation, temperature, relative humidity and visual conditions. Comfort sense (CS) rates rose from 8.26% to 46.8% and productivity increased about 26% after the chipboard workplace reconstruction. The expense of retrofit of the workplace was minimal compared with the comfort and productivity increases, and the investment callback period is less than two months.

Keywords: workplace, indoor environment, comfort, productivity, improvement

1. INTRODUCTION

It is well known that comfort and productivity are greatly related to indoor environment. But comfort is the feel of human beings that is affected by extensive factors such as individual's temper, character, indoors environment, which is difficult to quantitative. While productivity is more difficult to measure and varies from job features because the outputs and inputs are typically greatly diverse with job nature. G. Clausen and D.P. Wyon found the significant improvements of different indoor environmental factors on office work performance with higher budget levels [1]. In China, the indoor environment of the office in intelligent building has been noticed and the annual office cost is about 5280 RMB per m^2 floor area [2]. However, the comfort and productivity research on manufactory workplace, which is the physical and organizational system supporting workers to create value, is not always comprehensive and systematic available yet in China. Workers' labor states are dependent on the indoor environment, the outputs measures and the adaptability capabilities of the individuals. The relationship between the indoor environment and productivity in manufactory is closer compared with that of office buildings.

In addition, it is estimated by World Health Organization (WHO) about 30% new buildings can't meet the indoor environment requirement and even bring occupants' complaint. In recent years, more and more attention was focused on indoor environment, comfort, productivity and economic effects. The basic qualitative relationship of among these elements has been ascertained. The human mind, sprits and physiological action are all affected by indoor air quality (IAQ), temperature sense, lighting and sound, which bring different comfort perception, thus influence the productivity [3]. Consideration productivity is the organizational effectiveness, which is definition of units creating outputs from inputs. The impact on indoor environment to economics is very huge, which

includes absent from work, strike and out of work or diseases. However, it is very difficult to determination the exact relationship between the comfort sense and productivity. Human beings are not the machines who are always behaving the same way under the same conditions, and it is obvious that different productivity levels are obtained even at same indoor environment for different skilled people. And even under apparently identical work conditions, different comfort sense and productivity values may be achieved for the same person. In addition, the productivity for the same work item is not constant throughout the operation period, and varies at different stages of the production [4]. These indoor environment elements for influence productivity involve heating, ventilation and air-conditioning system (HVAC), lighting and acoustic systems [5].

The general impact on comfort and productivity for the indoor environment was firstly discussed in the paper. Then a real chipboard workplace was investigated for the indoor environment based on subjective vote and objective physical parameters measurement before and after the chipboard workplace retrofit. The chipboard workplace was about 2707 m^2 with 160 workers. In our investigation, several aspects including air velocity, temperature, relative humidity and lighting were improved and evaluated. Finally, the relationship of indoor environment, comfort and productivity were determined, and the investment payback period for indoor environment improvement was calculated.

2. METHODS

2.1 Chipboard Workplace And Indoor Environment Description

The chipboard workplace locates in Guangdong province, south of China. These chipboards are utilized as the package materials for displays and furniture. The dimensions of chipboard workplace are 83.3m, 32.5m and 8.4m(length × width × height). The total area is 2707 m^2. Six doors are utilized for materials and occupants entrance. 24 identical windows installed in the wall are about the dimensions 2m and 3m (height × width). The rooftop is opaque with material of asbestos tiles. Although 34 fans are installed in walls and ceiling, the airflow between indoors and outdoors is natural ventilation. 160 workers are divided into four groups to shift from 8:00 AM to 6:00 PM, but they are often overtime to 10:00PM. Because the thermal produced by machines is very huge, the air temperature rapidly increases after the machinery startup. Especially, if all the machines operation at the same time, the air temperature commonly gets to 35^0C even to 43^0C in hottest summer months. In addition, violent noise by machines makes workers distracted and inaudibility for talking. Most of this noise is high frequency metal friction and vibration production. Lighting problems are also existence in this chipboard workshop, although the rooftop is opaque, and the window area is enough, the lightness in cloudy day is deficient. Total more than 40 fluorescent lamps are installed in chipboard, but the power is only 2.5kw. Because of deficient lighting, the workers feel fatigue and out of line during in operation machines.

2.2 Indoor Environment Sense Subjective Evaluation

On order to determine the comfort level, subject vote method and objective indoor climate parameters measurement were implemented. The subject thermal response was carried out by asking workers for a"comfort vote" on the descriptive table that is same as the ASHRAE scale [6]. Similarly, lighting and noise comfort vote was also obtained on the middle of August in 2004, which is hottest month in a year. In our survey, 148 workers vote the comfort sensation with 117 effective replies. No one satisfies the indoor thermal environment. The results are indicated in Table 1.

From the Table 1, the sum of unacceptable, very uncomfortable, uncomfortable and little comfortable numbers of thermal sense and noise sense votes get to 98.3% and 84.5% respectively. For lighting sense, the rate of common and comfortable is only 7.78% together. It is proved that the indoor environment is greatly bad.

Tab.1 Indoor environment comfort Vote (%)

	thermal	lighting	noise
unacceptable	59.0	42.7	52.1
very uncomfortable	18.8	15.4	13.8
uncomfortable little	17.1	25.6	13.7
Comfortable	3.42	8.55	12.8
common	1.71	2.56	8.55
comfortable	0	5.13	6.84
total	100	100	100

2.3 Indoor Environment Objective Test

Subjective evaluation index, which is so-called predicted mean vote (PMV) represents most workers sense but not all those of people. It is well known the PMV index can't be completely representative for optimal thermal comfort sense, and even PMV value equals to zero, the 5% dissatisfaction rates occurs [7]. Because the limitation is existence for subjective evaluation, the objective test is also indispensable in order to reflect quantitatively the indoor environment. Five aspects measurement were carried out consideration of the main elements of indoor environment conditions in terms of indoor temperature, air velocity, relative humidity, noise and lighting level. In addition, the outdoor climate parameters were also recorded at the same time for the sake of comparison. For the sake of achievement accurate indoor environment parameters, representative climate test points should be carried out as shown in Fig.1.The measurement methods are adoption based on U. S. Air Force Technical Order (T.O.-00-25-2-3).

Five measurement points are indispensable for the workplace area more than 100 m^2 (Table 2). Temperature and relative humidity test are carried out at the location of 1.2m height distance floor, which is equivalent to the height of operation tables or workbenches, every 9m^2 (3m×3m) a measurement point with 5 seconds continuance at every measurement in hygrothermograph.

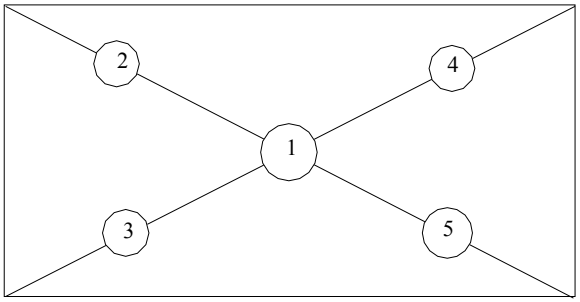

Fig. 1 Test points of chipboard workplace

Tab. 2 Test methods about cleanness extent in chipboard workplace

floor area	test point
A≤15 m^2	point 1 and point 2
15<100≤100 m^2	point 1, 2,3, 4, 5
A> 100 m^2	every 9 m^2 (3m×3m) adding a point

The test points and time about noise and lighting are same as temperature with noise meter and luminometer respectively. Consideration of machines as main heat sources, besides above-mentioned test points, every point is added at the place of machines. The mean indoor temperature is the average value of all the points measured. A set of data are recorded every 15 minutes with 5 seconds continuance during shift hours in terms of temperature, air velocity, relative humidity, lighting and noise.

The most basic features of local outdoor climate is long and hot summer, violent solar radiant and drippy. The hottest month, August, the mean outdoor air temperature is more than 32^0C-35^0C. In addition, cooling load is required in whole years even the coldest month in chipboard workplace. The indoor air temperature is always higher than that of outdoor (Fig.2). From 9:00 AM to 6:00 PM, the average temperature difference is more than 3^0C-5^0C due the heat storage in the envelope and machines heat production. Especially, from 11:00 Am to 15:00 PM, the indoor air temperature often more than 38^0C. In this hot environment, no one can operate properly machines always.

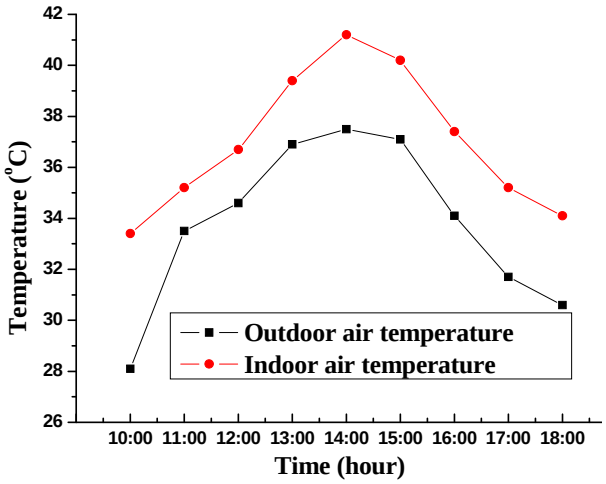

Fig.2 Indoors and outdoors hourly temperature in a chipboard workplace

2.4. Productivity Calculation

For the productivity calculation, both products quantity and quality are considered due to the products is scaled as piece in the chipboard workplace. Here the productivity is not the strict one as above-mentioned because of without consideration cost, that is, the inputs of raw materials and energy is neglected, and moreover, the responding tax is also ignored due to products increase. If the outputs of qualified products increase during the same time periods under the same worker numbers and machines numbers, then the productivity is consideration increase. If consideration of tax, labor price, operation and material cost diversification, the calculation of productivity may be very complicated. The products of quality eligible chipboard and the unit price are objective functions of productivity. The following equations indicate the productivity of the chipboards.

$$S = \frac{1}{N}\sum_{i=1}^{N} O_i \tag{1}$$

$$P = p_c \cdot S \tag{2}$$

$$I_r = \frac{P_2}{P_1} \times 100\% \tag{3}$$

Where, O_i is the qualified products quantity of ith worker every day piecework; N is the number of investigation workers; S is the average qualified products by N workers; p_c is the unit market price in present China; P is the averaged outcome (productivity) in the chipboard workplace, which can be expressed in money. P_1 and P_2 average productivity before and after the workplace retrofit respectively. So I_r is the increment rate of productivity. If the workers' medical treatment charge reduces due to indoor environment improvement, then it means the outputs increment as well, because the medical treatment expense can be also conversion to the products price.

3. INDOOR ENVIRONMENT IMPROVEMENT MEASURES

It is analyzed that solar heat gain by envelope and machines heat production are the main heat sources in chipboard workplace. Because of the close rooftop, poor indoor environment greatly bothers workers' mind and efficiency even no one will to work in the chipboard workplace. The machines are installed on the floor, and heat air rises floating near the ceiling to shape a heat air cover. Although all the windows are open and plenty of fans are running in the workplace, the heat removal mainly relies on natural convection through the window. That is to say, although the air velocity of working zone in workplace by fans is about 0.4~1.5 m/s, the heated exhausts air elimination between indoors and outdoors are basically through natural ventilation. As our suggestion, the indoor thermal environment is improved with following measures. (1) Two paths of fresh air with the flowrate 60000 m^3/h respectively, which passes a cool water pond to achieve heat and humidity exchange, and then the cooled air enters into workplace from the two side door. (2) The rooftop of chipboard workplace is reconstructed to open style. Total 64 holes with diameters 80cm are added on the rooftop, and these holes installed vanes with rain shields. Due to the heat pressure function between indoors and outdoors, the "funnel effect" will rise, which can induce air eject. Thus, the reasonable route forms between the fresh outdoor air and heat exhaust indoor air.

In order to improve lighting, 24 metal halide lamps and fluorescent lamps with total power 7.5kw are installed in the walls at the height from 2m to 7m

distances to workplace floor. Local illumination is added near the lathes. Comparatively big angle of view is retained in avoidance of direct swimmy. The interior surface of workplace wall was renewed and rendered with white paint. Background brightness is also strengthened for the conveniences identification and alleviation eye plague. That is, background lighting and local lighting is combination for visual comfortable. There are no special noise improvement measures to be carried out, but all windows are kept always open to release sound energy. The total retrofit investment about chipboard workplace is about 120,000 RMB (about 15,000 dollars).

4. RESULTS

4.1. Indoor Environment Improvement Analysis

The indoor thermal environments were obviously improved. The average indoor air temperature decrease 3^0C to 7^0C, and highest temperature was no more than 34.7^0C, achievement 8.3^0C decrease compared with that of the former workplace. During the most time of the operation, the indoor air temperature were higher than outdoor air temperature, but it was opposite from 12:30 to 15:30 (Fig.3). Calculation showed the outdoor thermal load by solar and envelope and interior thermal load by machines and workers were 61.5% and 38.5% respectively.

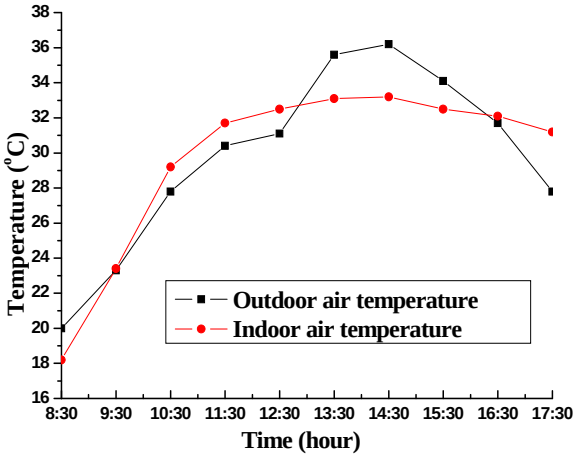

Fig.3 Outdoor and indoor air temperature comparison after retrofit

The indoor air velocity recorded was 0.3 m/s to 2.2m/s, and the air velocity fields showed better uniform. Most hot airflow was directly removed vertically through dormers in the rooftop. The fresh air was fully mixed with indoor air, and the reasonable indoor air routes were built. The averaged air age was about 28.7 minutes through trace gas method.

Lighting quality relies on uniform lighting distribution, daylight, color temperature (quality of lighting spectrum), and lighting glare. Visual comfort is a condition of the mind, which expresses satisfaction with the visual environment. To achieve visual comfort, the visual demands of the task should not exceed the ability to see adequately. Mixed illumination assured favorable lighting character in chipboard workplace. The rate of global and local illumination was 0.21. The average illumination varied from 102 lx to 585 lx, and max illumination is 2218 lx. The lighting reflect rate of ceiling and walls were 0.23 and 0.57 respectively.

Average 3.7 dB to 13.1 dB noise reduction was recorded. But the problems of reverberation were settled in some extents. Low frequency and high frequency noise accounted for 32.1% and 67.9% respectively. Acoustic improvement was not so obvious because of machines vibration and noise echo indoors.

4.2 Comfort Vote Improvement

A comfort sense survey was carried out in term of thermal, noise, lighting and drought vote. The most obvious change of comfort sense was lighting, and then thermal sense. The favorable and good vote rates for lighting was 40.1% and 19.4% respectively, while the unacceptable rate was only 20.8%, which was corresponding to the test results. The thermal comfort sense was also greatly improved, and the favorable and good rate accounted for 5.04% and 17.3% respectively, while the unacceptable vote decreased to 41.7%. The comfort sense vote rate sum on “favorable, good and common” for thermal, lighting and noise increased to 58.3%, 79.2% and 46.8% respectively after the workshop retrofit. The average comfort sense increased from 8.26% to 61.4%. It was noticed although the noise comfort sense apparently increased to 46.8%, the

unacceptable vote still accounted for 53.2%. This was greatly different from the measurement results. The figure of vote about noise was far better than field records, which might be insinuative mind effect.

4.3 Productivity Comparison

The productivity could be obtained according to the equation 1 to equation 3. Only output was calculated in the paper, which was a little bit different from common methods as the complication and veracity consideration. Total inputs involving tax, materials, energy, labor wages and other cost, which was not all always available for some information, because the benefits was the only pursuit for the investors. As our primary estimation as the Chinese average price at present market, the monthly productivity was more than 565000 RMB ($70625). If the average worker numbers in a month were 160, the productivity per worker per month was 3531 RMB ($441), which was 728 RMB ($91) increment. The mean productivity increased about 26%. The indoor environment retrofit cost was about 120,000 RMB ($15,000), so the investments return period was 1.03 months. Even consideration of other cost, the real investments return period was no more than 2 months.

5. DISCUSSION

Although great advance was obtained, the indoor environment in chipboard workplace in this investigation was still more improvement. However, more investment was required to keep the comfort.

5.1 Thermal Comfort

Whether an occupant is comfortable or not depends on diverse factors such as temperature gradients, relative humidity, air movement, occupant's activity level and dress quantity. Thermal comfort sense is most influence elements for productivity, which also determines the worker's mind and temper. Even average 3^0C~7^0C air temperature decrease was obtained, the thermal comfort perception was still to 41.78% unacceptable. Although the cool load is required even in coolest month due to the chipboard location in south of China, if adoption enough air-conditioning system, it is not impractical.

5.2 Visual Comfort

Favorable visual comfort is indispensable for safety and health, especially in workplace, shadow and obscuration caused by deficient lighting will bring hallucination, which is main reasons of body hurt by machines. Moreover, deficient lighting will also bring eye fatigue. For chipboard workplace, the natural lighting is not a problem most time, but for night and cloudy days, some local places have no good illumination. Since lighting can affect a person's comfort level, lighting designs are increasingly tailored to ensure personal comfort while providing effective illumination in workplace. Metal halide lamps and fluorescence lamps are best selection, while low- pressure and high-pressure sodium lamps, mercury and incandescence lamps may be not appropriate. Lighting has enormous potential to influence an occupant's perception of space. A variety of lighting factors contribute to the productivity.

5.3 Acoustic Comfort

When background noise in workplace becomes distracting or even oppressive, the ability of workers to understand each other is diminished. Two methods can be adopted in chipboard workplace. One is reduction noise source, avoidance the machines noise production. The other is noise absorb and attenuation by shelter or sound absorption materials. Workers' that are properly equipped with high performance acoustical materials with ears will perform better because they are more comfortable and less distracted. Ideally, workplaces should be free of noise and sounds that distract from the tasks at hand. The connection between acoustics and productivity is also a strong relationship. In chipboard workplace, no specific noise measures were adopted. But the echo problems of noise were partly settled due to rooftop holes and windows open.

5.4 Productivity

In addition, health and safety is beyond all doubt

related to productivity. The worker's health and safety is the promotion and maintenance of the highest degree of physical, mental and social status. Favorable indoor environment will prevent worker ill, and at the same time, reduce error operation and waste products. It is the time for China to regard occupational diseases. The lowest limitation of indoor environment should not be damage for the operators in workplace. Occupational health is an important strategy not only to ensure the health of workers, but also to contribute positively to productivity, quality of products.

6. CONCLUSION

The paper analyzed the indoor environment impact to productivity in a chipboard workplace in south of China. In the case, the expense of retrofit of the workplace is only 120,000RMB ($15,000), but the average comfort sense rate changes from 8.26% to 46.8%, and productivity increases about 26% by the chipboard workplace reconstruction. The indoor environment investment is insignificant compared with the benefit of comfort and productivity increase, and the investment callback period is less than 2 months. It is proved that the investment is absolutely deserved for indoor environment improvement like the workplace building from the comfort and productivity consideration.

REFERENCES

[1]. G. Clausen, D.P. Wyon, The combined effects of many different indoor environmental factors on acceptability and office work performance[C]. In: Proceedings of The 10th International Conference on Indoor Air Quality and Climate. Beijing, China, Sept. 2005. 368-372.

[2]. ZS Li, GQ Zhang, JL Liu. Impact of indoor environment on comfort and productivity in intelligent building [C]. In: Proceedings of The 10th International Conference on Indoor Air Quality and Climate. Beijing, China, Sept. 2005. 314-317.

[3]. Li Zhi-sheng, Zhang Guo-qiang, Liu Jian-long. Impact of indoor environment on comfort and productivity of the occupants [C] (In Chinese). In: Proceedings of the 1st International Forum on Indoor Environment Safety and Sustainability. Changsha, China. Dec.2003, 263-266.

[4]. Lam KC, Lee D, Hu T. Understanding the effect of the learning–forgetting phenomenon to duration of projects construction [J]. International Journal of Project Management .19(2001),411–420.

[5]. Hedge, A. and M. Navai. Indoor Environmental Quality Effects on Productivity. http://eqs.syr.edu/htm/_research/Indoor%20Environmental%20Quality%20Effects%20on%20Productivity.pdf. [2003-05].

[6]. Fanger, P. O., Ostergaard, J., Olesen, S. et al. The effect of man's comfort of a uniform air flow from different directions [J]. ASHRAE Transactions, 1974, 80(2), 142-147.

[7]. Derek C. C, Li Baizhan. productivity and indoor environment [C]. Proceedings of Healthy Buildings. Espoo Finland: Vol.1, 1(2000): 629-634.